



Radiometric Survey of Granite-Gneiss Rocks for Potential Hazard Indices and Radiogenic Emission Detections: A Case Study of Akunu-Akoko and Ayere Areas, Southwestern Nigeria

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Abstract

High resolution ground radiometric survey across some Granite gneiss rocks in Akunu (Location 1) and Ayere (Location 2) basement complex in Southwestern Nigeria was carried out using Gamma ray Spectrometer to detect the concentrations of the most common radioactive elements and to evaluate the potential hazard that the emission could pose on humans. The basic radiometric data is presented and it is evident that bedrock geology exerts a controlling influence on the broad response characteristics of the naturally-occurring radioactive elements. From the results of the concentrations of these radionuclides, the mean value of K (0.44-1.08%), U (2.09-2.7ppm) and Th (11.1-12.1ppm) in location 1 is lower than the K (2.74-3.68%), U (3.5-4.3ppm) and Th (5.9-21.3ppm) in location 2 respectively with exception of location 2 traverse 2 with the lowest concentration of Th. To assess the radiation hazard indices of the granite gneiss such as absorbed dose rate and Annual Effective Dose Equivalent (AEDE) to humans were calculated and found to be below the internationally recommended values. The absorbed dose rate ranged from 7.8-8.32nGy/hr and from 5.52-9.07nGy/hr for Akunu and Ayere respectively within percentage variation of 10-27%. The Annual effective dose rate (AEDE) ranged from 6.77-18.36μSv/y for the area surveyed. The results indicate that the radiation hazard from the radiogenic emission of granite gneiss in the area studied is not significant based on standard parameters. Therefore there is no immediate radiation health hazard to living communities in nearby areas.

Keywords: Radiometric method, Radionuclides, Hazard indices, Granite-gneiss, Akunu and Ayere, Nigeria.

Introduction

Radiometric survey measures the spatial distribution of three radioactive elements that is Uranium (U-238), Thorium (Th-232) and Potassium (K-40) in the top 30-45cm of the earth's crust (Gregory & Horwood, 1961).

The abundances of K, Th and U are measured by detecting the gamma-rays produced during the natural radioactive decay of these elements and the abundance of these radioactive elements changes across the earth's surface with variations in rock and soil type.

The basic purpose of radiometric surveys is to determine either the absolute or relative amounts of Uranium, Thorium and Potassium in the surface rocks and soils which are of importance in geologic mapping and mineral exploration (Urquhart, 1988 and Faure, 1977).

Radioactive elements occur naturally in the crystals of particular minerals. Since the energy of gamma rays is related to the source radioactive element, they can be used to measure the abundance of those elements in an area. So by measuring the energy of gamma rays being emitted in an area, we can infer the presence of particular minerals in the earth's surface.

The distribution of radioelements in rocks and soils is discussed by Dickson and Scott (1997) and is further reviewed by IAEA (2003). Potassium (K) is a major component of the Earth's crust (2.35%). It is an alkali element and shows a simple chemistry. The major hosts of potassium in rocks are potassic feldspars (e.g. orthoclase microcline with ~13%) and micas (e.g. biotite and muscovite with 8%). Thorium (Th) is a minor component of the Earth's crust (~12 ppm). Major thorium bearing minerals (e.g. monazite and zircon) are stable during weathering and may accumulate in heavy mineral sand deposits. Thorium freed by the breakdown of minerals during weathering may be retained in Fe or Ti oxides/hydroxides and with clays. Uranium (U) is a reactive metal with a low average abundance in the Earth's crust (~ 3 ppm). It may be present in rocks as the oxide and silicate minerals, uraninite and uranothorite; as trace amounts in other minerals or along grain boundaries possibly as uranium oxides or silicates.

$$\text{Therefore } N_0 e^{-\lambda t} \cdot N_0 \frac{1}{2} N_0 t_1 \frac{0.693}{\lambda}$$

The three main types of radiation arising from radioactive decay are alpha, beta and gamma rays. The emission of an alpha or beta particle usually leaves the new nucleus in an excited state and the

surplus energy is radiated as gamma rays (Minty, 1997). These are quanta or photons of energy which are neither very penetrating because they possess neither charge nor mass. The major assignment of a structural geologist in the field is to delineate as correctly as possible the rock units existing in the field (Amadi et al., 2012).

Gamma ray surveys are used in several fields of science. They are used for geological, geochemical, and environmental mapping, and allow the interpretation of regional features over large areas (IAEA, 1991, 2003). They may be used to estimate and assess the terrestrial radiation dose to the human population and to identify areas of potential natural radiation hazard.

The aim of this study is to determine the distribution of gamma radiation emanating from radioactive elements contained in Granite-gneiss rocks present in two localities in Ondo State and Kogi State which are Akunu-Akoko and Ayere respectively. The two neighboring communities are within the basement complex of Southwestern axis of Nigeria. This investigation was carried out in order to know the emission rate of the most common radiogenic materials (K, U and Th) emitted by rocks and Total Radioactive count of these elements for geologic correlation of rocks. Also, the Absorbed Dose rate and Effective Dose rate of each radioelements to deduce the potential hazards from radionuclides admissible by humans from rocks within the study areas.

Geologic Setting of the Study Area

The study area (Akunu and Ayere) lies within Latitude 7°35'N - 7°45'N and Longitude 5°55'E - 5°60'E (Fig. 1 and Fig. 2) of the Greenwich meridian in the basement complex of Nigeria and underlain by Southwestern Nigeria's basement complex rocks. The Basement Complex rocks of Nigeria forms a part of the African crystalline shield which occurs within the

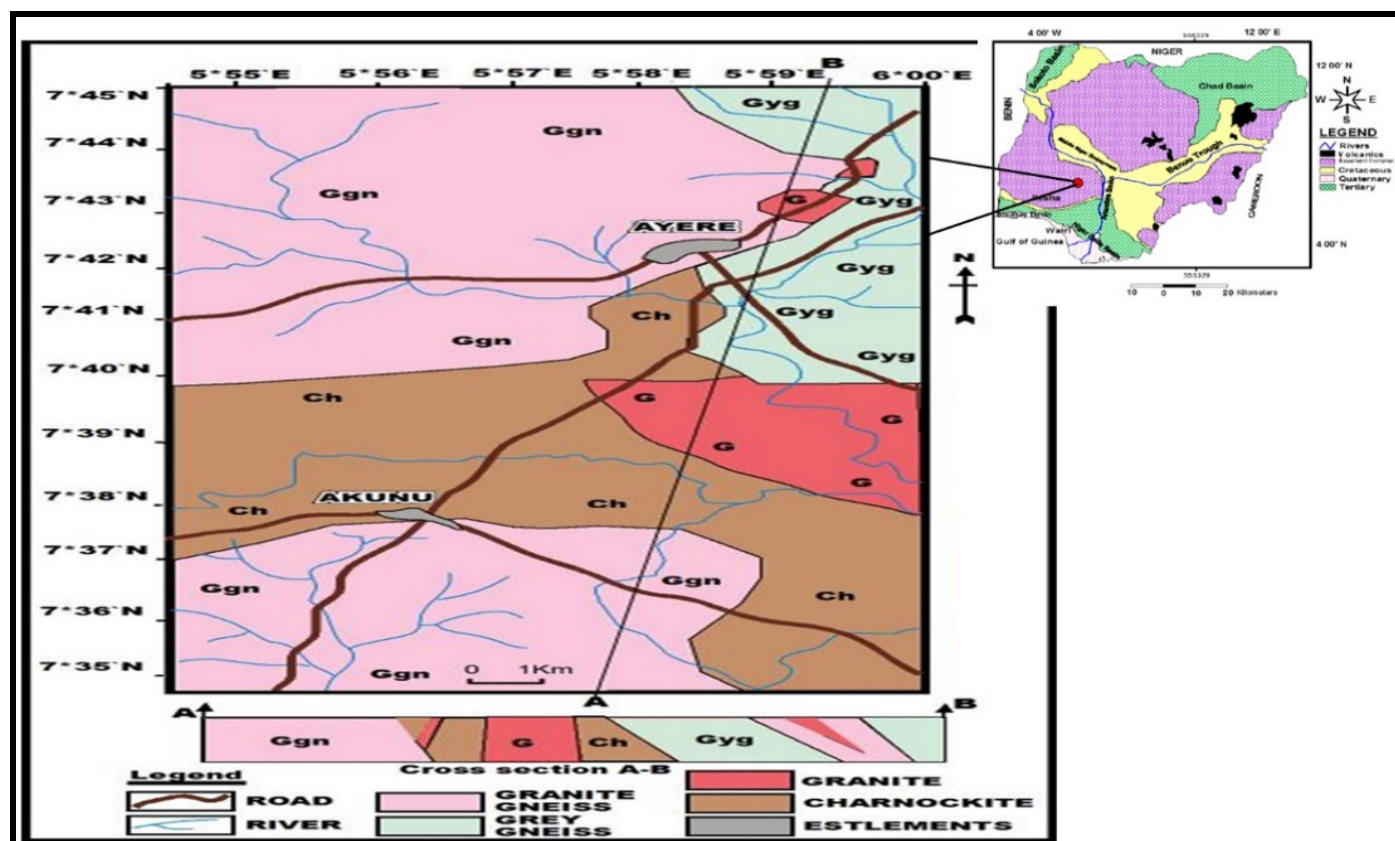


Fig. 1. Geological Map of the Study area produced during the mapping exercise to locate every possible areas where the Granite gneiss rocks could have outcropped.

Pan African mobile belt that lies between the West African and Congo Cratons and South of the Tuareg Shield which were affected by the Pan-African orogeny (Oyawoye, 1972).

The geological history of the areas is similar to the structural evolutions that had affected the basement complex of Nigeria. The rocks present in the area include Granite, Porphyritic granite, Charnockite, Grey gneiss, Granite gneiss, Pegmatite and other felsic and mafic intrusive.

The predominant rock types in the study areas are majorly: Granite, Grey gneiss, Granite gneiss and Charnockite. Granite gneiss and Charnockite are about 70-80% of the total rock types present in the Study area. The Granite gneiss are the most predominant rock in the Southern and Northern parts

and the Charnockite occurred within the central parts of the study area. The Grey gneiss were seen within some locations not wide spread like the Granite and Charnockite. The Pegmatite within the areas form an intrusion into the older rock of granite gneiss that occupies some part of the areas.

Materials and Methods

Radiometric method involves the measurement of naturally occurring radioactive emission (Gamma ray) emanating from rocks. The gamma rays are detected by a spectrometer, which counts the number of times each gamma ray of particular energy intersects it. The energy spectrum measured by the gamma ray spectrometer is in the range 0-3MeV and energies of geological interest lie between 0.2 and 3 MeV. Peaks in the spectrum can be attributed to Potassium (K),

Thorium (Th) and Uranium (U), the number of gamma ray counts across the whole spectrum is referred to as the Total Count (TC) (Milsom, 2003). This is one of the most cost-effective and rapid techniques for geochemical mapping of the radioactive elements: Potassium, Uranium and Thorium.

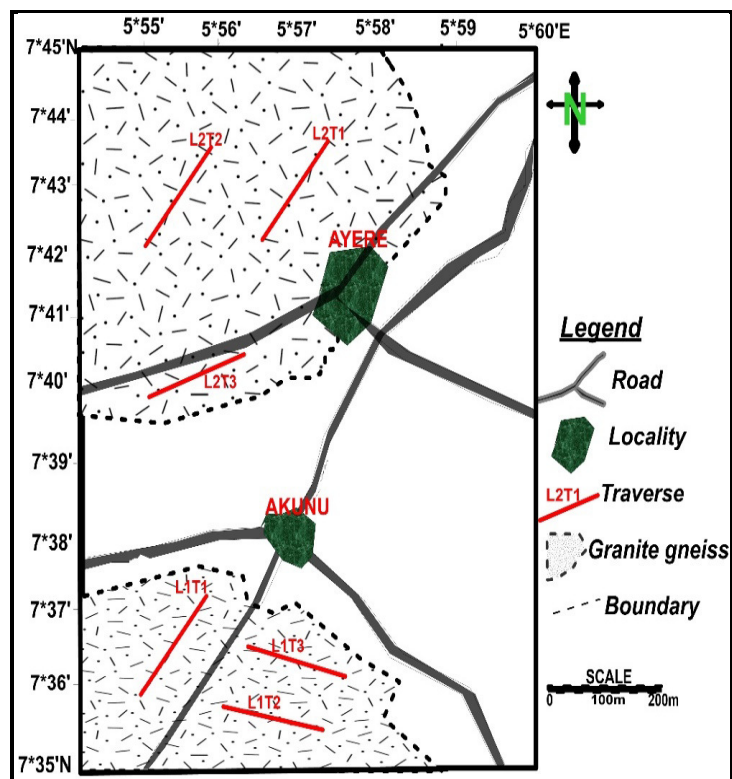


Fig. 2. Location Map of the Study Area showing how data were acquired on some of the Granite gneiss along profile lines (3 traverses from each location to sum to a total of 6 traverses of widespread 200m each).

The Readings were taken along six (6) traverses at intervals of 5m. Three (3) traverses were covered in Akunu (location 1) and Ayere (location 2) respectively; each traverse has a total length of 200m. Two (2) readings were taken at each point and the average values were used for the K (%), U (ppm), Th (ppm), Total Count (TC) (cps) values, and Dose rate. The instrument used for the measurement is a highly portable hand held detector (Gamma Ray Spectrometer).

The data recorded on the field were computed using Microsoft Excel to determine the mean values for Absorbed Dose Rate and Effective Dose Equivalent (AEDE), and some of the results were plotted for pictorial view and representation.

The Absorbed dose rate (D) was calculated using the following expression (UNSCEAR 2000):

$$D = 0.462C_U + 0.604C_{Th} + 0.0417C_K \dots \dots \dots (3)$$

The annual effective dose equivalent (AEDE) received outdoor by a member of the public is calculated from the absorbed dose rate by applying dose conversion factors of 0.7Sv/Gy and occupancy factor of outdoor and indoor was 0.2 and 0.8 respectively (Veiga et al 2006).

$$AEDE \text{ (outdoor)} (\mu\text{Sv/y}) = D \text{ (nGy/hr)} * 8760\text{h} * 0.7 \text{ Sv/Gy} * 0.2 * 10^{-3} \dots \dots \dots (4)$$

The results of the Total Count (TC) with their Coordinates for all traverses in each locality were imported into Oasis MontajTM (Grid and Image tool in Geosoft® software), the total count images were created after micro-levelling the entire data set to remove any Apparent Residual errors. These images were generated by employing mini-curvature gridding.

A Ternary RGB colour models were produced from the software: Potassium, Thorium and Uranium were assigned to the green, red and blue respectively because the blue tends to reduce the poorest signal-to-noise ratio of Uranium channel.

Results and Discussion

The results of the Total Mean values for K (%), U (ppm), Th (ppm), Dose rate, Absorbed Dose rate and Effective Dose rate are shown in Table 1. These values were computed from the large results collected on the field and from those calculated with Microsoft Excel. The scattered diagrams were plotted for all the

radioactive elements in respective traverse to show the distributions, trends with their highs and lows for better correlation in the radioactivity of both localities. The mean values of K (%) in Akunu are considerable low from about 0.44-1.8% compared to Ayere with 2.74-3.68%. Location 2 has a very high K content that an increase with distance away from Location 1 i.e. the trend in the increase is due north of the study area.

For U, the mean values in both areas are in the same trend of increasing order of values from 2.09-2.31ppm (Location 1) and fall back to 2.7ppm (L1T3). The trend increases with the composition of U and extend towards location 2 with values ranging from 3.5-4.9ppm, very high when compared to the values along the three traverses in location 1.

Th mean compositions of the rocks are very high when compared to U. Traverse 1 of the two locations has the same Th values (12.1ppm); indicating that the variation in their compositions are almost the same because both still retain them. Traverse 2 and 3(location 1) have slight difference of 0.3ppm (i.e. the rocks have almost the same Th-bearing mineral compositions). The increase in Th in location 2 fall from 12.1ppm to a very low value (5.9ppm), indicating that the rock/residual soil has low terrestrial gamma radiation or emission due to geologic processes. The robustness in Th-rich Granite gneiss rock is evident along traverse 3 (location 2) with the high mean value of 21.3ppm. This increase suggests that the richness of Th could have resulted from the terrestrial gamma radiation or due to incorporated minerals from other rocks within the transition phase zone between Charnockite – Granite gneiss (Figure 1).

The Mean Total Count (TC) (cps) of gamma radiation in the study area gently increases in tens with values from about 360-386cps throughout all the traverses. The increase in TC is 0.6cps between L1T1 and L1T2 then later fall with decrease of about 3.5cps between L1T2 and L1T3. The difference in increase of about

0.8cps between L2T1 and L2T3; and difference in decrease of about 7.0cps and 6.2cps between (L2T1-L2T1) and (L2T3-L2T2) respectively, this is a little bit higher than the former. Therefore, one can say that the TC in location 1 is lower to that of location 2. The aforementioned situations that contributed to low K, P and Th in location 1 are attributed to same factor that resulted to the decline in TC.

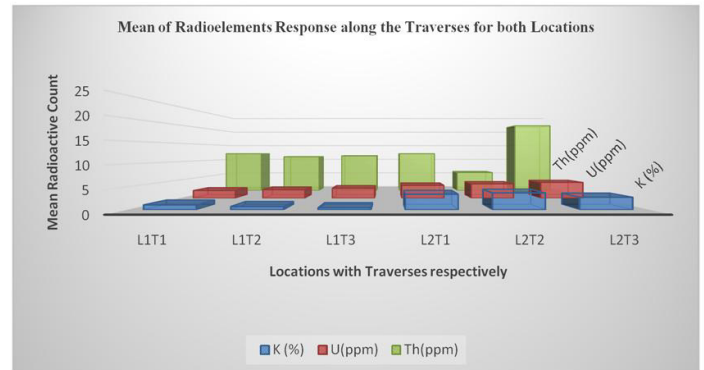


Fig. 3. 3D bar plot showing the increase in the level of K (%), U and Th (ppm) for the two locations. The K and U bars increase toward the last traverse in location 2. The Th bars increase started from L1T1 and decrease uniformly to L2T1 with sharp fall to L2T2 and increase back to about 21ppm.

Therefore, from the Table 1 and pictorial view (Figure 3) one can deduce the summary in Table 2. Figure 4, 5 and 6 give the pictorial views of the radionuclides emitted by respective elements (K, U, and Th) for traverse 1, 2 and 3 respectively of length 200m with spacing of 5m each for the two locations investigated. These are shown to corroborate the data presented in Table 1.

For Traverse 1, the K radiations emitted (blue) for location 1 increase uniformly with lows from 0.025% (15m, 35m and 40m) to highs of about 0.25% (95m), but in location 2 the trend is from lows of 0.2% (20m) to highs of 5.1% (65m). The U (orange) in location 1 has lows of about 0.05ppm (20m, 75m, 115m and 120m) with highs of about 5.1ppm (40m). At location 2, the trend of U increases to highs of about 8.5ppm (160m). The Th (ash) for location 1 increases from 4.95ppm to about 20ppm (195m), but for location 2

Table 1. Total Mean Values of Radionuclides from Granite gneiss.

Location Point	Mean K (%)	Mean U (ppm)	Mean Th (ppm)	Mean Total Count (cps)	Dose Rate	Mean Absorbed Dose Rate (nGy/hr)	Mean Aede (μ Sv/y)
L1T1	1.08	2.09	12.1	369.1	55.8	8.32	10.20
L1T2	0.72	2.31	11.1	369.7	50.7	7.80	9.57
L1T3	0.44	2.7	11.4	366.2	50.2	8.15	10.01
L2T1	3.4	3.5	12.1	385.4	94.9	9.07	11.12
L2T2	3.68	3.9	5.9	378.4	86.1	5.52	6.77
L2T3	2.74	4.3	21.3	384.6	114.4	14.20	18.36

***L1, L2, T1, T2, T3 implies Location 1 (Akunu), Location 2 (Ayere) with Traverses (1, 2 & 3) respectively. K, U, and Th imply Potassium, Uranium and Thorium respectively.*

the trend in distribution of Th is peaked to highs of about 25.1ppm (starting point).

Table 2. Summary of the Radionuclides emitted in the study area.

Location	Mean K (%)	Mean U (ppm)	Mean Th (ppm)
Akunu-Akoko	T1>T2>T3	T1<T2<T3	T1>T1<T3
Ayere	T1<T2>T3	T1<T2<T3	T1>T2<T3

*Total Count (TC): L1T3<L1T1<L1T2 L2T2<L2T3<L2T1

In Figure 5 (Traverse 2 of the surveyed areas), the trend in the distributions of the radionuclides fall have count rate of 25ppm (location 1) and 12ppm (location 2) with respect to figure 4 showing that some of the values are likely low. The lows and highs of U and Th are distinctive and well pronounced in location 2 but less for U with exception of Th in location 1.

In Figure 6 (Traverse 3 of the surveyed areas), the trend in the distributions of the radionuclides rise back to count rate of about 20ppm (location 1) and 62ppm (location 2). The Th has very distinctive peaks in both locations to about 61ppm.

The averaging of the sum of lows and highs of respective radionuclide produced the mean values in Table 1. The uniformity in the table and the scattered plots show that the radiation level of K, U and Th varied in the granite-gneiss rocks surveyed.

The radiometric data are first summarized in terms of colour images obtained from Minimum Curvature Grids. In order to avoid image colour bias, the radiometric images have been cut to the shapes of the survey patterns. Figure 7 shows the radiometric data in terms of Total Count (TC) which is a measure of total radioactivity over the spectrum. The images shown use an equal-area normalization of the colour scale. The data indicate the composite radiogenic activity of the formations. It is evident that there is a significant geological control of the radiometric responses observed. The high response values (2.7cps) and (9.0cps) for location 1(Akunu) and location 2 (Ayere) respectively show the TC (cps) emitted by these radiogenic materials. Even with their low response values (-3.4cps) and (-28.3cps) for Figure 7a and 7b respectively, spatial variations are detected. The low decrease in values of the TC (cps) on the legend of the TC images for locations compared to values in table 1 resulted from the filter

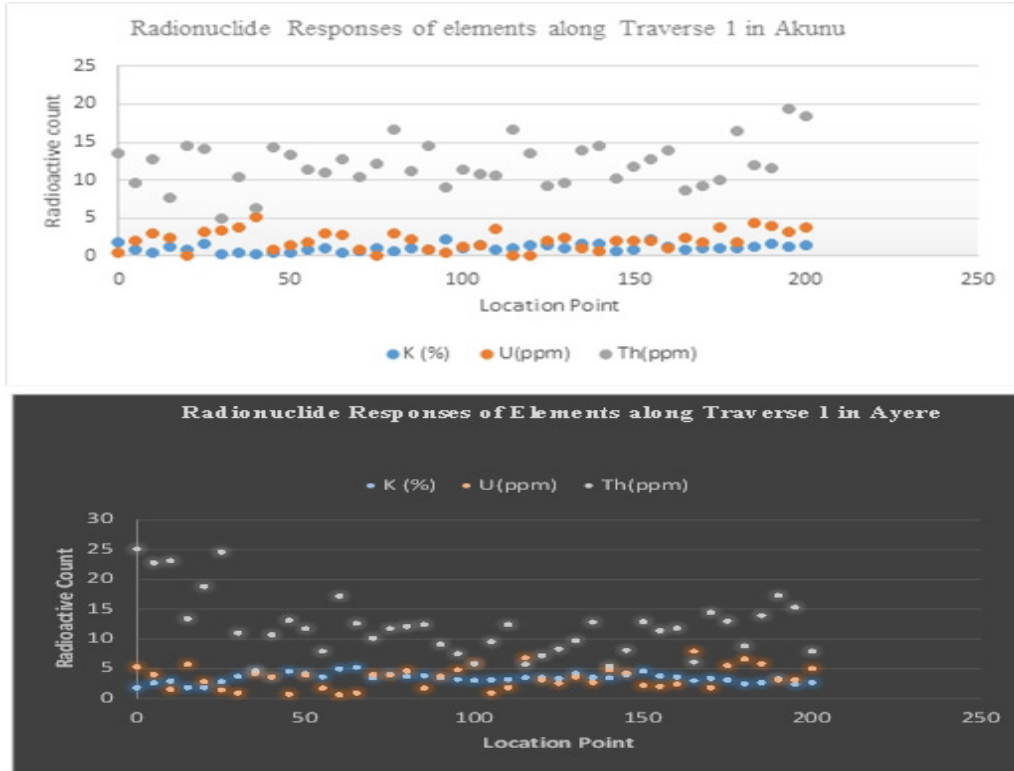


Fig. 4. The graph of radioactive count against Location point for L1T1 (White) and L2T1 (Black).

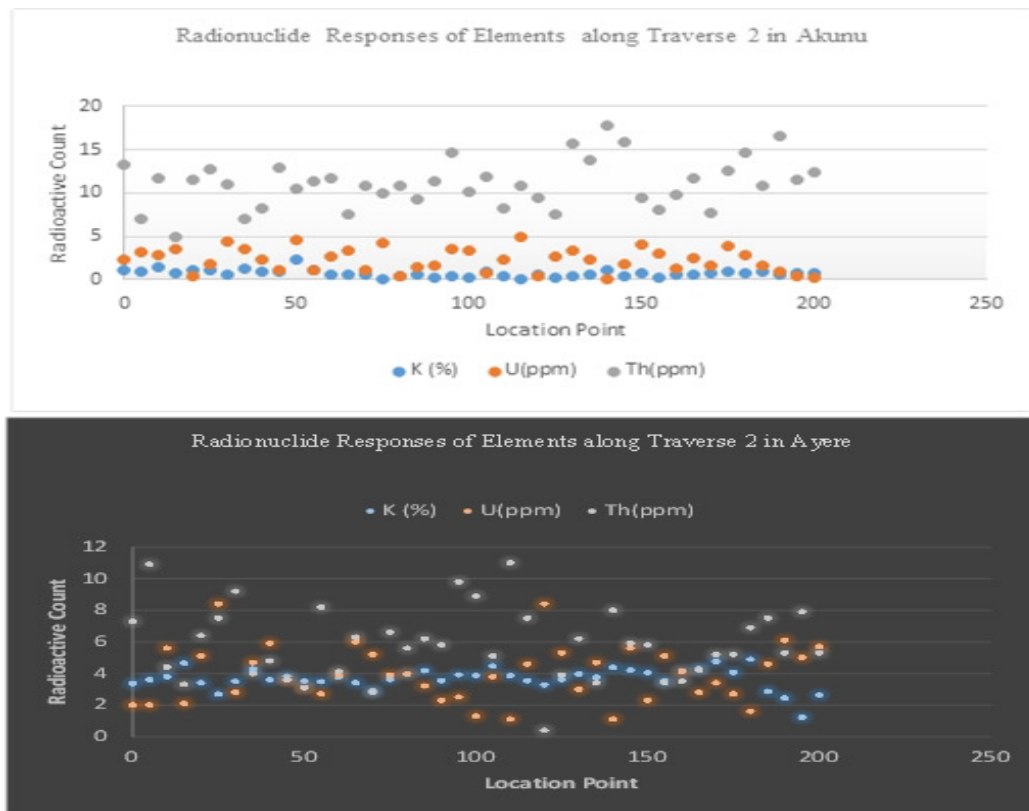


Fig. 5. The graph of radioactive count against Location point for L1T2 (White) and L2T2 (Black).

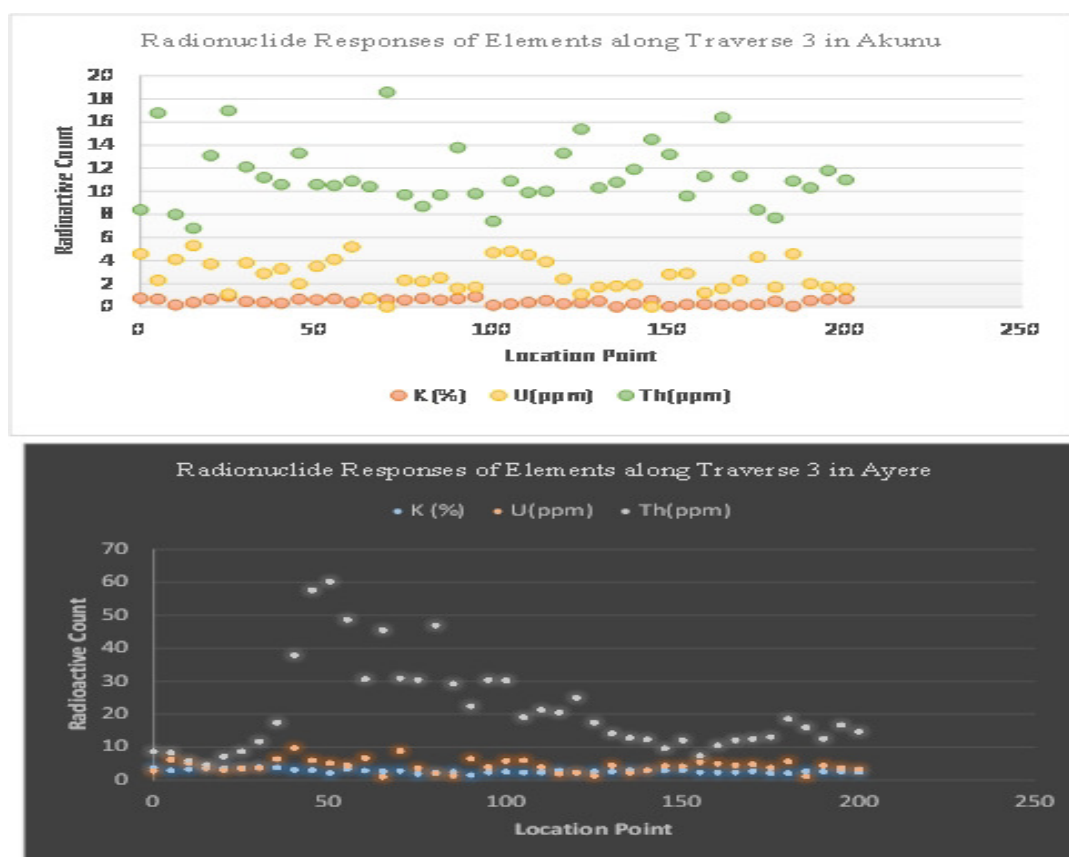


Fig. 6. The graph of radioactive count against Location point for L1T1 (White) and L2T1 (Black).

applied to acquired data for gridding on OASIS Software to remove spurious background noise and levelling to finally enhance signal to noise ratio.

The contributions from the 3 radioelements Potassium, Uranium and Thorium are summarized in the Ternary image (Figure 7). The Ternary image is a normalized (to an equal-area histogram) 3-way colour stretching of the contributions from the individual radioelements with red representing Thorium (Th), blue representing Uranium (U) and green representing Potassium (K). The presentation is a standard method in radiometric processing and interpretation (IAEA, 1991). In areas where all three radioelements concentrations are low, the Ternary image shows black; when all three concentrations are high, the Ternary response tends to white. The limiting behaviour (i.e. the 3-elements highs and lows) in the

Ternary image is also reflected in the high and low zones within the Total Count (TC) images of Figure 7. The Ternary image, while containing more noise, is able to reveal more subtle features in relative to radioelements contributions. In terms of equivalent radionuclides concentrations, the response is dominated by Thorium (i.e. areas denoted by Th, A, C and E on the Ternary Image). Portions marked A, C and E are areas with Thorium concentrations of about (65-90%) ppm. The Granite-gneiss also show a spatially complex set of radiometric signatures with a strong Thorium response evident across some significant areas of the study area. Also, the richness and robustness of Th being mapped better on the Ternary images have been proved true when compared with Table 1.

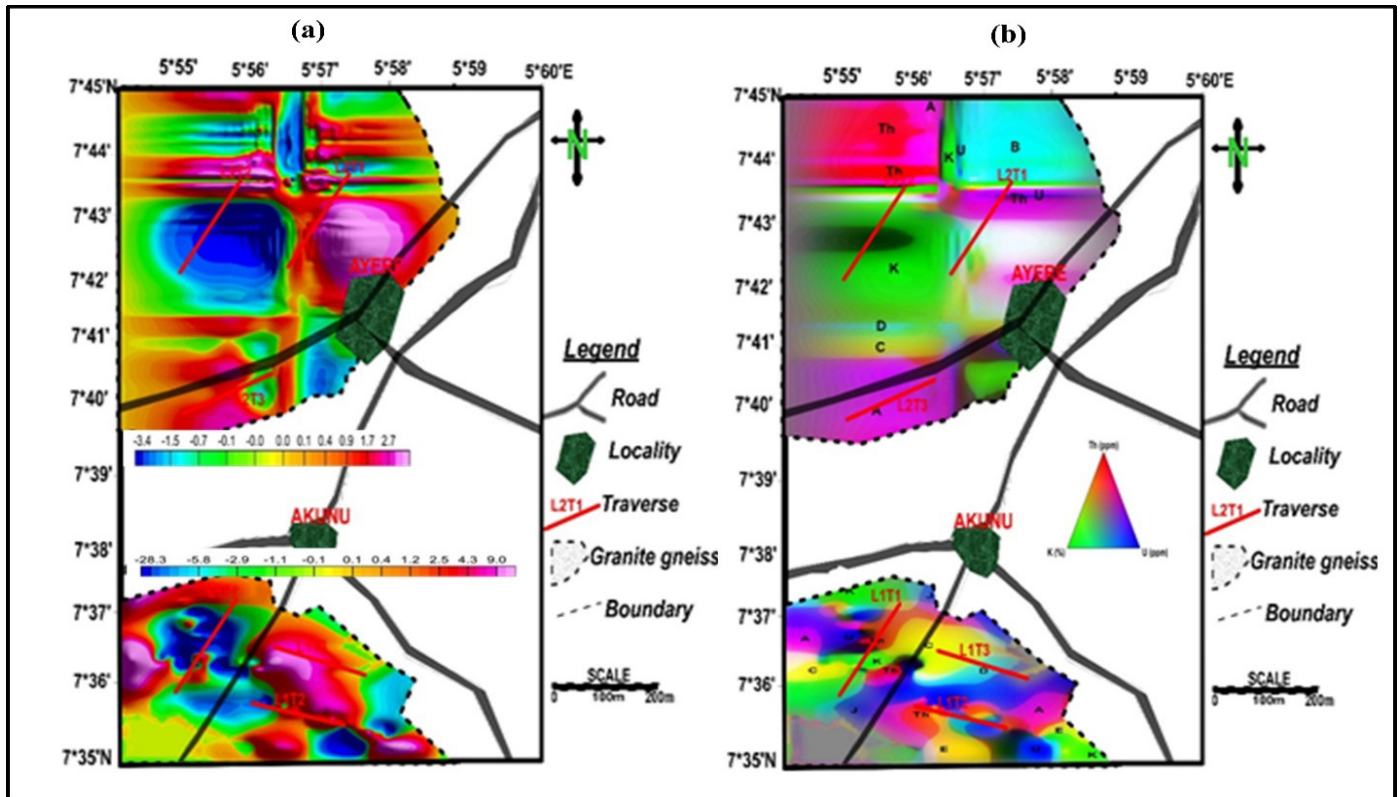


Fig. 7. The Map of the Study Area showing the Total Count (TC) and the Ternary images in (a) and (b) respectively. These are shown to correlate, for distribution of highs and lows TC (cps) in (a) and the distinctness of the radioelements (K, U and Th) on the Ternary image in (b).

In detail particularly, strong and diagnostic Potassium signatures (K) are found in the Granite-gneiss in Ayere and are likely to be generated by some of the undeformed potassic feldspar minerals. Interestingly, the Ternary character of the Granite-gneiss rocks observed in Akunu (Figure 7a) with a significant Uranium response (areas denoted by U (90-100%); B and D (45-60%) on the image map) appears to be distinct from that observed on the Ayere (Figure 7b).

It is also worth recording the gamma-ray exposure/dose levels obtained from the survey data to deduce some certain parameters for the hazard indices. The ground-level distribution of dose rate will follow that of the Total Count data shown in Table 1. The ground-level dose rates calculated for the data have a mean of 55.8, 50.7, 50.2, 94.9, 86.1 and 114.4 for respective traverses in the study area with maximum of 114.4.

The radiological hazard from radionuclides contained in the granite-gneiss rocks within the study area was assessed and with the estimated absorbed dose rates were plotted in pictorial representations (Figure 8a & b). The mean percentage (Figure 8a) varies from minimum of 10% (L2T2) to 27% (L2T3) as maximum. The bar plot (figure 8b) also gives a clearer picture to the trend of the radiated Absorbed dose rate in surrounding, the trend falls uniformly from T1 to T3 in Akunu (L1), then rises at T1, falls at T2 and appears peaked at T3 in L2. Therefore, one can say that the Mean Absorbed Dose rate of the study area has minimum of 10% (5.52 nGy/hr) and maximum of 27% (14.2 nGy/hr (nano Gray per hour); and Ayere (L2) has the highest amounts. Variations in the Dose rate as seen in the granite-gneiss rocks are due to the nature of the geological formations.

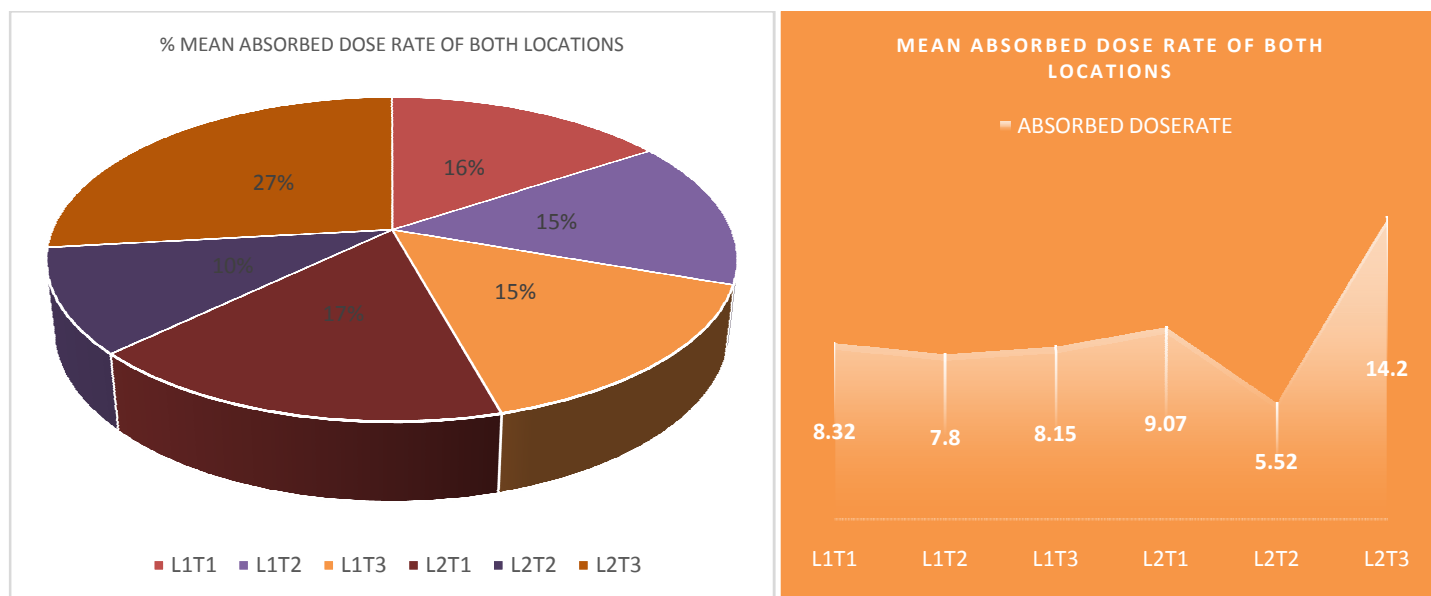


Fig. 8. (a) Percentage (%) Mean Absorbed Dose rate. (b) Bar plot of the Absorbed Dose rates Mean.

The effective dose (AEDE) for the different locations traverses in the rocks in this study has mean values of 10.2, 9.57, 10.01, 11.12, 6.77, and 18.36 $\mu\text{Sv/y}$ (micro Sievert per year) for respective traverses (Table 1), which is far below the worldwide effective dose of 70 (Orgun et al., 2007).

By way of reference, the typical absorbed dose rate due to background cosmic rays, at sea level, is about 32 nGy/h (IAEA, 2003). The results show that the H_{ex} (External Hazard Index) are below the limit of unity, meaning that the radiation dose is below the permissible limit of 1mSv/y recommended by IAEA (2007). The values of the radiation hazard parameters from this current study are not high compared to the world averages and the recommended values and therefore unlikely to cause additional radiological health risks to the people living in the areas studied.

Conclusions

The study has shown the efficiency of radiometric survey in detecting the radiogenic emissions of most common radioactive elements (^{40}K , ^{238}U and ^{232}Th) in Granite-gneiss rocks and studying the hazards that

these may pose to health of people living in nearby areas.

On compares between L1 (Akunu) and L2 (Ayer), the results obtained in L1 for K ranged from 0.44-1.08%, U from 2.09-2.7ppm, Th from 11.1-12.1ppm and Total Count (TC) from 366.2-369.7cps, while that obtain in L2 for K ranged from 2.74-3.68%, U from 3.5-4.3ppm, Th from 5.9-12.3ppm and Total Count (TC) ranged from 378.4-385.4cps.

The high resolution of this method has been proven in the Total Count (TC) and Ternary images produced for both locations in the study area for its worthiness and robustness in geophysical investigation. The TC images helped to show the depletion of the radionuclides and for well correlation of the total emitted radionuclide in the study area. The Ternary images on the other hand showed the contributions from the 3 radioelements K, U and Th distinctively based on the concentration of each and were able to show that Th has the highest and K lowest.

The variation in the radioactivity of the study area could be attributed to the rocks, most especially low concentrations in L1 (Akunu) most have been because of weathered nature/mineralogical compositions of the

rocks than L2 (Ayere). These variations are always associated to acidic intrusive and metamorphosed rocks.

The absorbed dose rate of L1 ranged from 7.8-8.32nGy/hr and L2 from 5.52-9.07nGy/hr respectively of percentage variation of 10-27%. The effective dose rate (AEDE) ranged from 6.77-18.36μSv/y, these values are very low compared to world standard values for radiological hazard in humans. Therefore, the study areas pose no risk to humans living in nearby areas. However, the impact of radioactive elements on subsurface groundwater quality of the area requires a separate investigation.

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